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VLS GROWTH OF GaSe NANORIBBONS BY MOCVD

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CONTEXT

Gallium selenide (GaSe) is a layered semiconductor from the III-VI family which presents a tunable direct band gap of 2 eV. Optoelectronic properties of this material have already been demonstrated for photodetection applications [1-3]. Nevertheless, actual fabrication methods are based on exfoliated layers and there is a lack of large scale, good quality, elaboration method for 2D materials in general.

Working with one-dimensional objects could be an alternative to synthesize very good crystalline quality objects. Here, we demonstrate the VLS growth of GaSe nanoribbons (NRs) by MOCVD on 300 mm SiO2/Si substrates. The crystalline quality of these structures is investigated by HRTEM. Devices are realized on single NR, and optoelectronic properties are studied via photoluminescence and electrical characterizations.

III-VI FAMILY

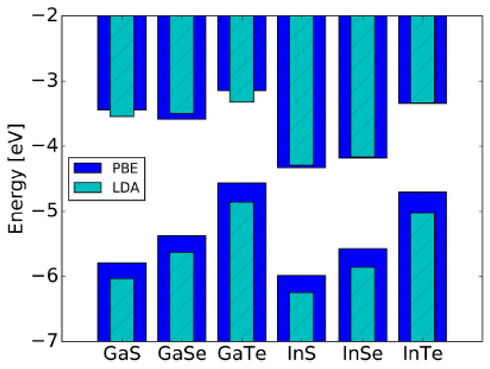


Fig. 1 : III-VI semiconductors family. Band gap alignment for monolayers of MXs materials [4]

- III-VI layered semiconductors family is composed by post transition metals monochalcogenide MXs (with M: Ga or In, X: S, Se or Te).
- Different direct band gap energy for each binary compounds.
- Possibility to combine them and tune the band gap by creating heterostructures.

GaSe PROPERTIES

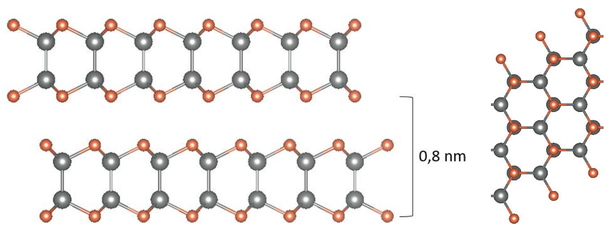


Fig. 2 : Tetra-layer structure, Se-Ga-Ga-Se, side and top view

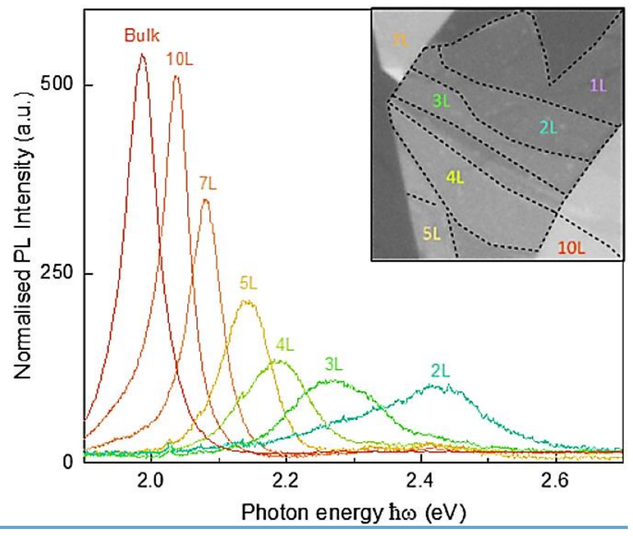
STRUCTURE

- Tetra-layer structure
  X-M-M-X (X=Se, M=Ga)
- Inter-layer spacing of 0,8 nm [6]

OPTOELECTRONIC

- GaSe is generally p-type [7]
- E_g(GaSe) : 2,00 eV (bulk) [8]
  - Direct band gap from some monolayers to multi-layers.
- Variation of band gap energy depending on the layer number
  - Allow to cover a large spectral range.

Fig. 3 : PL spectra of GaSe with different thickness [5]



GROWTH

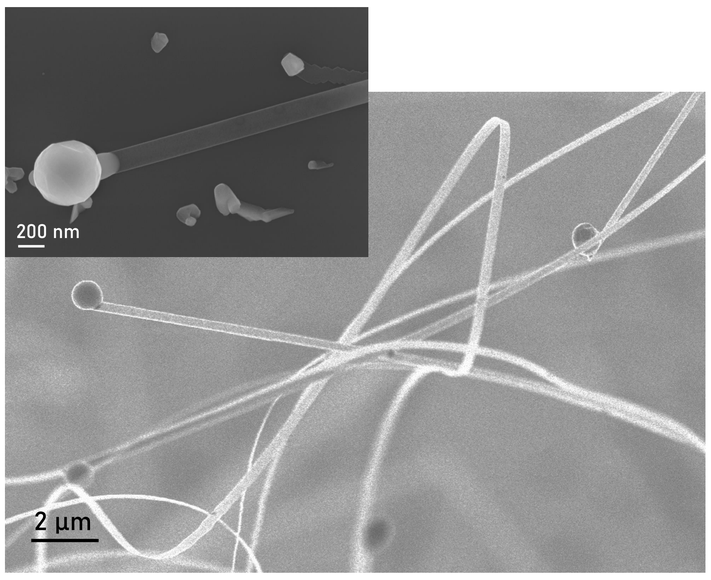


Fig. 4 : SEM images of as-grown NRs. In inset, a high magnification image shows the droplet sitting on top of a NR

- Growth by MOCVD in industrial *Applied Materials* reactor on 300 mm SiO_2/Si.
- Indium droplets are used as catalysts to initiate the growth.
- Observation of the catalyst at the end of the nanoribbons
  - Consistent with Vapour-Liquid-Solid (VLS) growth mechanism.

CRISTALLINE QUALITY

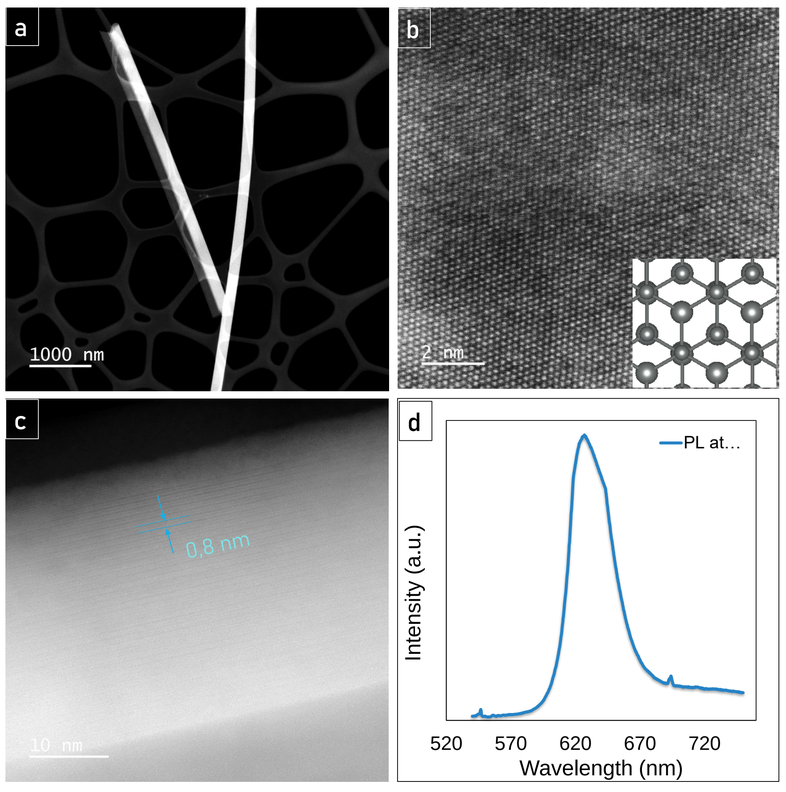


Fig. 5 : (a) STEM observation of dropcasted NRs on TEM membrane. (b) High magnification TEM image of the center of a nanoribbon. (c) High magnification TEM image of a NT. Inte-layer spacing measured to be 0.8 nm. (d) PL spectrum of several NRs

- GaSe nanoribbons :
  - Several nanometres wide (average width : 300 nm)
  - Several micrometres long
- Very good crystalline quality observed by HRTEM.
  - No defect observed.
  - GaSe monolayers stacked along z-axis.
- Very few nanotubes have been observed. Majority of grown structures are nanoribbons.
  - Measured inter-layer spacing of 0.8 nm.
- Energy gap measured by PL on several nanoribbons
  - Eg = 1.97 eV

INTEGRATION AND OPTOELECTRONIC PROPERTIES

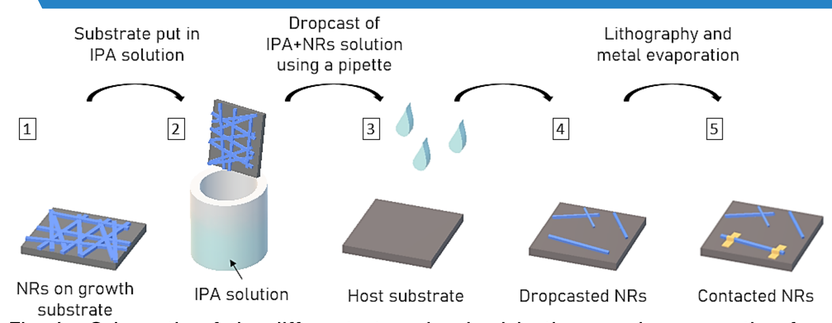


Fig. 6 : Schematic of the different steps involved in the sample preparation for electrical characterization.

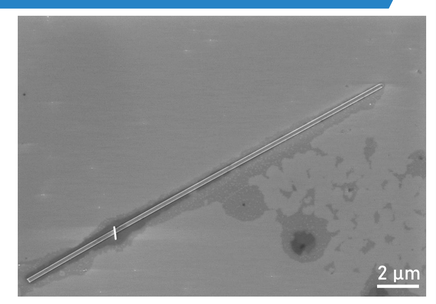


Fig. 7 : Typical SEM image of a dropcasted NR

- Sample preparation follows the indicated steps in Fig 6. Contacts are realised by e-beam lithography and Ni-Au are evaporated as electrodes materials.
- Electrical measurements have been led under illumination (white light) and in dark, for temperatures ranging between 25 and 100°C.
- The current level increases with the temperature. Though, the current level is low.
  - A photodetection behaviour is observed.
  - Current level might be limited either by very low doping level of the NRs or bad contacts/GaSe interface.

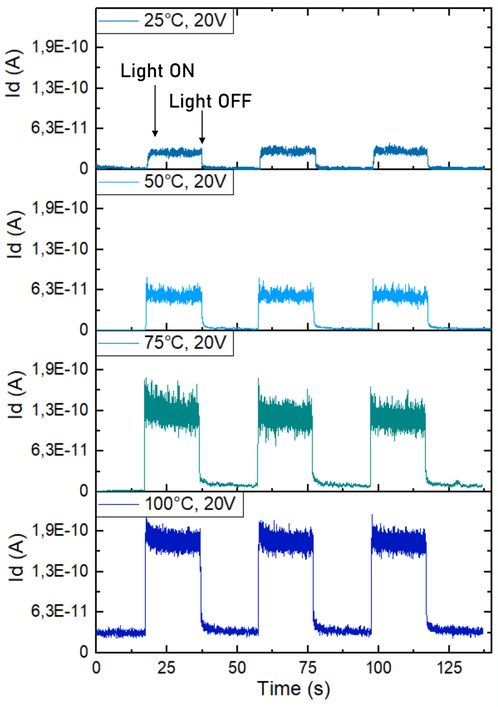


Fig. 8 : I(t) characteristics for a NR, at different temperatures (25 to 100 °C), bias : 20V

CONCLUSION

Very good crystalline GaSe-NRs are synthesized via VLS mechanism in 300 mm MOCVD reactor. A photodetection behaviour is observed for a single NR.

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